continues now from the cloud and intensifies the process involved in forming drops.

It must be concluded that radiation is a factor in all rain-making processes but the methods by which it induces or influences precipitation are necessarily complicated and imperfectly understood. The slightly greater loss of heat by radiation from water vapor or cloud at night unquestionably accounts in part for the more frequent and heavier nocturnal precipitation. C. S. Durst[3] has ventured the following hypothetical explanation of a possible action of radiation:

Below the critical height,[4] however, any particle which forms will lose heat by radiation and will consequently tend to cool the air in its neighborhood with the effect of increasing the deposition of ice or water. Thus above this critical height condensation will tend to be evaporated; below it, drops will tend to grow, until they either fall through the surrounding atmosphere or reduce its temperature to such an extent that instability arises.

Whatever the ways in which radiation influences cloud formation or precipitation, it remains that data about radiation from water vapor in the free air are essential to a better understanding of the processes involved.

[3] Quarterly Journal, R.M.S., April 1933, vol. 59, pp. 125-129.

[4] The height below which there is a net loss of heat by radiation and above which there is a net gain of heat by absorption of radiation from below; above 6 km in southeast England.

NACREOUS AND NOCTILUCENT CLOUDS

By W. J. HUMPHREYS

[Weather Bureau, Washington, September 1933]

Two interesting and important papers recently have been published by Carl Störmer [1] on clouds in the stratosphere, a region commonly free from clouds of every kind.

There are two types of these clouds:

a. The nacreous (from the name common to several languages for mother-of-pearl), figure 1, which occurs at heights of 20 to 30 kilometers above sea level, and

b. The noctilucent (a name already well established), figure 2, which forms at about 80 kilometers above the earth.

The first of these, the nacreous, resembles in places an alto-cumulus lenticularis, or, more exactly, an alto-stratus lenticularis, though presumably it contains much less cloud material than either of these generally does, and is brightly colored like a glorified iridescent cloud. The second, or noctilucent, type seems usually, if not always, to resemble some sort of cirrus. It is silvery, or bluish-white, in color and has been seen in the middle to high latitudes of both hemispheres, but only when the lower atmosphere was in the shadow of the earth and the cloud in full sunshine.

Both these types of stratospheric clouds had been observed and carefully studied long before Störmer made the detailed measurements of them that form the basis of his valuable papers mentioned above; one, the nacreous, by H. Mohn, as early as 1871, and the other by O. Jesse as far back as 1885. Nevertheless their origin still is in doubt.

I propose here to develop a tentative hypothesis as to the origin of these clouds. It may be incorrect, and much of it is old, but even so a logically possible origin, however wide of the mark, is a better aid to the memory than no origin at all, and secures a more willing acceptance of the facts. This hypothesis is that they are produced by the condensation of water vapor just as are all the clouds of the lower atmosphere.

As is well known the stratosphere commonly is 25° C., or thereabouts, warmer, and its base several kilometers lower in high latitudes than in tropical regions. Owing to this temperature difference there obviously must be an interzonal (equator to poles and poles to the equator) circulaton in the stratosphere. Calculation indicates that near the height of 20 kilometers the pressure should be roughly constant the world over and the winds at that level therefore nearly zero, as observation shows them to be. Below this level of equal pressure and mininum wind velocity the air of the stratosphere must flow from the lower to the higher latitudes and next above it, to what height we do not know, counterwise or toward the tropical regions. Evidently this circulation necessitates a corresponding ascent of the air in the stratosphere over high latitudes, with, of course, a greater or less loss of temperature with increase of height. The lapse rate however will be kept small by radiation from below, provided the circulation is gentle.

Suppose the base of the stratosphere at latitude 60° N., say, is 10 kilometers above sea level; that at this level, and just above it, saturation obtains; that the temperature here is 228° A., and that the lapse rate in the stratosphere is zero up to 18 kilometers and then uniformly positive in the region where convection presumably is active. At what temperature would saturation over water (water assumed because these clouds are iridescent, implying diffraction by spherical droplets) occur in this air (specific humidity, or vapor fraction of air, constant) at the height of 25 kilometers, the level, roughly, of the nacreous clouds?

A little calculation shows this to be of the order of 205° A., a temperature that would be approached at the given height if the air in the stratosphere above the 18-kilometer level had a lapse rate of 2.9° C. per kilometer. If the initial relative humidity were only 50 percent instead of 100 percent as assumed, then saturation would occur at the same height, 25 kilometers, if the lapse rate were 3.6° C. per kilometer.

Hence, under the conditions here specified, most of which are in agreement with observations and none contrary thereto, it seems quite possible that in rather high latitudes a thin cloud might be formed in that portion of the stratosphere in which the upward component of the stratospheric interzonal circulation is most pronounced.

So much for the presumable origin of the nacreous cloud. It remains now to consider the noctilucent cloud. Assume that occasionally, at least, in fairly high latitudes the temperature of the upper air is: from 10 to 18 kilometers, 228° A.; from 18 to 25 kilometers, decreasing uniformly to 210° A., from 25 to 35 kilometers, 210° A.; from 35 to 40 kilometers, increasing uniformly to 315° A.; from 40 to 60 kilometers 315° A., and beyond this last level decreasing, 7° C. per kilometer, to an undetermined height. Also let the water vapor at every level be one part in 4,000 of all the gases present, the amount we have assumed to be present at the base of the stratosphere. Also let the composition of the air be substantially constant from the base of the stratosphere up to 100 kilometers, or more, above sea level, except for the variation in the amount of ozone present, the substance responsible for the high temperature, if it exists, at the levels of 40 to 60 kilometers. These suppositions are in harmony with the skip phenomenon of distant, loud sounds, and ozone and auroral observations. Then, if these assumptions are correct, saturation over ice (ice because these clouds do not show iridescence) could again occur and cloud begin to form at a height of 80 to 83 kilometers, roughly, and temperature of about 160° A.

[1] Höhe und Farbenverteilung der Perlmutterwolken, Geofys. Pub., vol. IX, no. 4, Oslo, 1932.
Height and Velocity of Luminous Night-Clouds Observed in Norway, 1932. Univ. Obsy. Oslo, 1933.

FIGURE 1.—Nacreous clouds. After sunset, January 13, 1932; Oslo, Norway, looking WSW. (C. Störmer, Photo.)

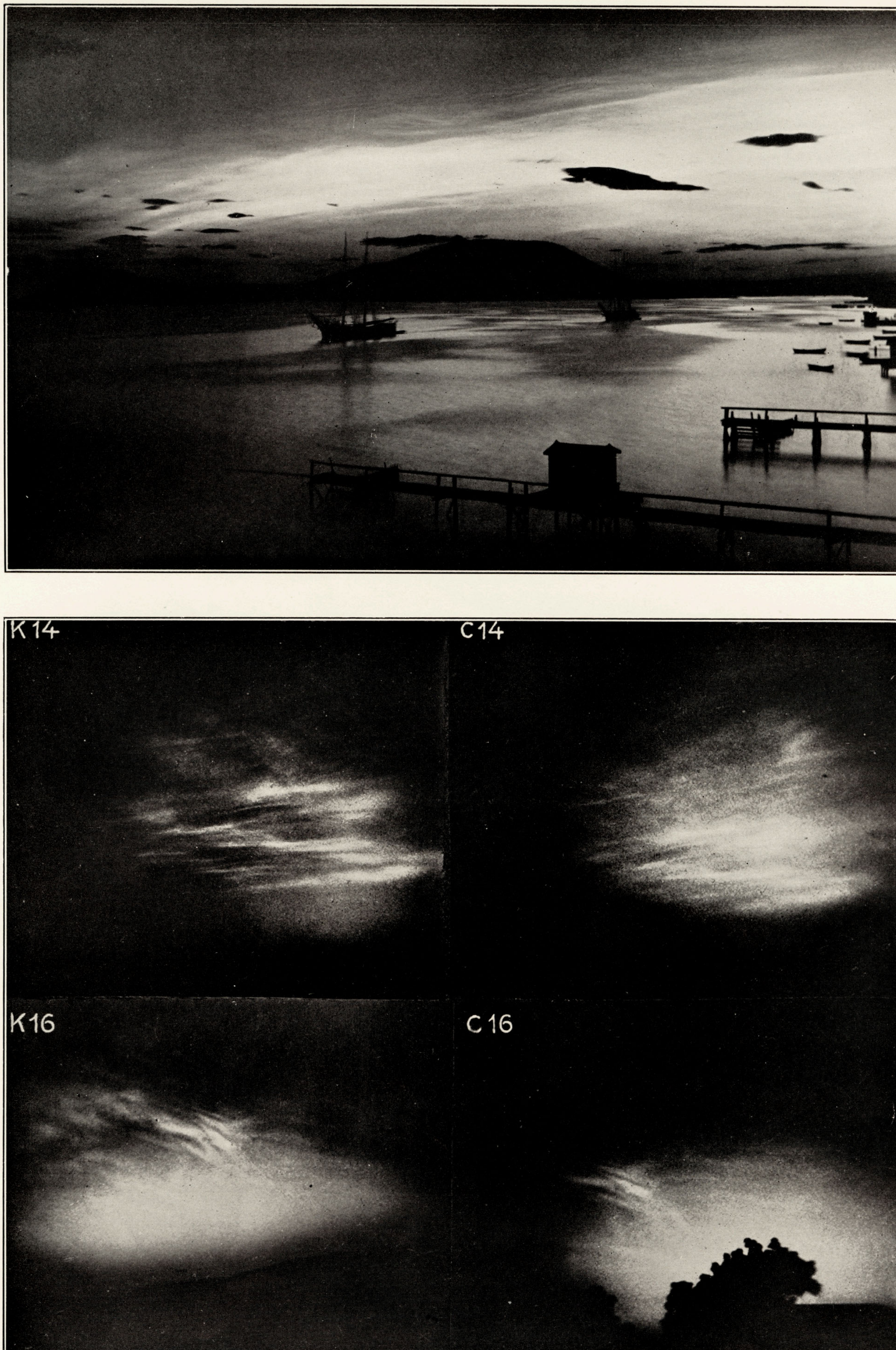

FIGURE 2.—Noctilucent clouds. *Upper*, near midnight, July 27, 1909; Drobak, Norway. (C. Störmer, Photo.) *Lower four*, near midnight, July 10, 1932. (Photographed by direction of C. Störmer.) K-14 and K-16, Konigsberg, Norway. (Busengdal, Photo.) C-14 and C-16, Oslo, Norway. (Tveter, Photo.) The C's and K's were taken simultaneously for determining heights.

If the temperature of the ozone layer is high, as now generally believed and here assumed, then clearly there must be marked vertical convection above it and a correspondingly rapid decrease of temperature with increase of height, or lapse rate, until that particular temperature is reached at which the loss of heat through radiation by a unit mass of the air is equal to its gain of heat by absorption of radiation, at which level a second, or upper, stratosphere will begin.

What the temperature of this second stratosphere is we do not know, but presumably it is lower than that of the first, or under, stratosphere because, mass for mass, its coefficient of absorption is less—less, by experiment, owing to its smaller pressure; and less, by theory at least, owing to its already lower temperature—theory indicating that absorption of radiation by a gas or vapor must decrease with decrease of temperature. At any rate, its temperature may, it seems, be quite low enough to occasionally permit of the formation of super cirrus clouds in its upper portion of sufficient density to be seen when illuminated by the sun while all the lower atmosphere is in the shadow of the earth and therefore free from glare.

As others have suggested, it may be that the water vapor put into the upper air by violent volcanic eruptions has been an important contributing factor to the production of the noctilucent cloud. Such explosions also add condensation nuclei to this high region, though that may be "carrying coals to Newcastle." We may assume that the volcanic water vapor is driven, partly by explosion but chiefly by convection incident to its own high temperature, into the warm ozone layer where none of it would condense, the temperature being too high, and that from there portions of it are carried on up by the convection that persistently must obtain in that region to the level of condensation.

But, we ask, can the water vapor of this source be worth considering—be more than the proverbial "drop in the bucket"? Perhaps so, for the quantity of water vapor given off by volcanoes is very great. It has been estimated, for instance, that during a certain consecutive 18 hours Vesuvius gave out enough water vapor to make a cubic kilometer of liquid water, an amount that would be many drops in the outer air bucket.

It is possible that carbon dioxide may have some part in, or be alone responsible for, the formation of the noctilucent cloud, but not likely, since to solidify it from an atmosphere in which it exists in the usual volume proportion of 3 to 10,000, and at the low pressure that certainly prevails at the height of 80 kilometers, would require a temperature of the order of only 100° A., a much lower temperature than we have any reason to expect at that level, and much lower, apparently, than would be sufficient to produce a cloud of ice particles.

If the above ideas are substantially correct, then the atmosphere consists of the following great divisions, counting from the surface up, namely: Troposphere, stratosphere, ozoneosphere, altotroposphere, and altostratosphere.

MORNING SHOWERS OVER THE GULF, AND AFTERNOON SHOWERS IN THE INTERIOR NEAR CORPUS CHRISTI, TEX.

By J. P. McAULIFFE
[Weather Bureau Office, Corpus Christi, Tex.]

A peculiar type of local shower condition occurs near Corpus Christi, Tex., during the summer months, and has such marked characteristics that it has attracted the attention of meteorologists, and sportsmen who visit this coast.

Following an almost cloudless night thundershowers begin forming off-shore over the Gulf about 3 to 4 a.m., and move slowly inland. As they advance toward shore these thundershowers break up into two main storms, one moving northwestward, and the other southwestward, invariably advancing toward the nearest land areas, which are in the directions mentioned. Very few of the storms move directly westward toward Corpus Christi Bay, nearly all appearing to avoid that water area. It is for this reason that the Weather Bureau rain gage records very little precipitation from these showers, as the gage is located on the roof of the Federal Building in down-town Corpus Christi about 1,000 feet west of the Bay. Copious showers occur northeast and southeast of the city during the early morning hours and often the thunderstorms become heavy. Drifting slowly westward these shower conditions reach the interior during the midday and afternoon, and copious and sometimes torrential showers occur north, west, and south of Corpus Christi. During the latter part of the afternoon the clouds dissipate, and by sunset the sky is usually cloudless. This condition is usually repeated 2 or 3 days in succession. The showers are scattered and moderate the first day, more general and heavier the second day, gradually decreasing in intensity and area until the third or fourth day, when no more occur.

When these showers prevail, the early morning air is sultry and the wind generally light, sometimes calm. When the showers reach the shore north and south of the city a moderate breeze that is unusually cool and invigorating comes in from the sea, and the air over the Gulf becomes clear, with visibility unusually good.

An outstanding feature of these thunderstorms is the time of commencement which is almost invariably within the hour following 4 a.m. First thunder usually is heard between 4 and 5 a.m., and the first shower reaches the mainland about 5:30 to 6 a.m. They also traverse almost identical paths as they approach the interior, and for that reason localities along that path have successive days with moderate to excessively heavy rains. In the main the showers are unwelcome, because they come in the cotton-picking season, and delay picking in the areas affected.

It seems that the same general cause, local convection, is responsible for the showers over the Gulf, before sunrise, and over the interior as the day progresses. Since the air is warmer by night over the Gulf than over the land thunderstorms then develop offshore; but as the soil becomes warmer than the water during the day the convection and consequent thunderstorms then occur inland.

Why the showers avoid the crescent-shaped Corpus Christi Bay is not fully understood. The theory is that the land breeze, coming from higher elevations (from sea level to 200 feet within 40 miles westward) converges as a rather strong descending and cool current over the Corpus Christi Bay region, cutting off convectional action in that area, and acting as a barrier to the advancing thunderstorm.[1]

The first showers are practically impossible to forecast, as there is no condition on the weather map to indicate when they will occur. After the rains have started, however, one may assume that the same condition will be repeated the following day, and probably the third day, and forecast accordingly.

[1] The course of the flow of the free air, hence direction of travel of a distrubance in it, is from "source" to "sink"; in this case from water to land. Therefore a storm headed toward the mouth of the bay is likely to be divided into two branches, each moving to, and then over, its nearest land surface.—Editor.